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THE EFFECT OF ELECTRONS, PROTONS AND ULTRAVIOLET RADIATION ON PLASTIC MATERIALS

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SUMMARY

The plastic films Aclar, Kapton and Teflon-FEP were irradiated with ultraviolet light, electrons and protons. Mylar with Astro Epoxy was irradiated by UV and Mylar with electrons and protons. FEP-adhesive combinations were subjected to UV. Changes in transmission were measured. All films coated with adhesives were darkened by UV. Kapton and FEP are most resistant to radiation, both UV and particulate. Aclar becomes very brittle. Mylar is darkened by electrons but not affected by protons. These results are applicable to work in solar cell cover materials.

INTRODUCTION

Solar cells for space use must survive irradiation by ultraviolet (UV) light, electrons and protons. As now manufactured, CdS cells are covered with Kapton, shown to be very stable to the space environment but also very low in overall transmission (64 percent) in the wavelength range where the solar cell is known to respond. For this reason, an effort has been made to find a more transparent plastic in this wavelength range (0.35 to 1.20 μm). Not only must this plastic be more resistant to ultraviolet radiation, electrons and protons, but also, if the film must be attached to the cell with an adhesive, the adhesive used must be resistant to radiation. Kapton, because of its transmission spectrum, serves as a very effective UV-protective filter for any adhesive used with it.

NASA-Lewis has tested many plastic films. This report includes results of UV irradiation of cover plastics (with and without adhesives). The plastics are Teflon-FEP, Kapton, Mylar and Aclar. Also included are results of electron and proton irradiation. The changes in the cover plastics have been determined by following changes in the transmission and calculating an integrated transmission to solar radiation over the wavelength range of interest (0.35 to 1.20 μm).

The UV tests were conducted in a vacuum of 3×10^{-6} torr and a temperature of 31°C. The light source consisted of ten 100-watt high-pressure mercury arcs and one two-watt low-pressure mercury arc. Some tests were conducted without using the low-pressure arc. The intensity of the source was 7.5 suns for wavelengths less than 0.30 μm (inclusion of the low-pressure lamp did not produce a

measurable change in intensity). Tests were conducted for times up to 9500 ESH.

The electron and proton irradiations were conducted at NASA-Goddard at the Van de Graaff facility. The pressure was 10^{-5} torr and the temperature was at ambient ($\sim 28^{\circ}$C). The electron energy was 1 MeV and fluences up to 2.6×10^{17} e/cm^2 were used. The proton energy was 800 keV and fluences up to 10^{14} p/cm^2 were used.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The films were irradiated by ultraviolet light in vacuum in a system described previously (1). The films were irradiated for a certain length of time and then removed from the tank and measured. The film transmission was measured using a Perkin Elmer model 350 spectrophotometer. Spectra were measured in the wavelength range 0.35 to 0.75 μm and the results extrapolated to 1.20 μm. It has been found that this procedure is valid (1). The average transmission over a small wavelength range is multiplied by the solar energy in this range. The results are then summed to yield an average transmission over the entire wavelength range of interest.

The light source used consists of ten 100-watt high-pressure mercury arcs, Hanovia type SH, and one 2-watt low-pressure mercury arc. This small lamp is enclosed in the vacuum chamber because 2 percent of its radiation is at 0.186 μm. The intensity of the source is 7.5 suns for wavelengths less than 0.300 μm. Details of the source and vacuum chamber are more fully described in reference 1.

The proton and electron irradiations were conducted at NASA-Goddard by J. Hirschfeld. The tests were conducted at 10^{-5} torr and ambient temperature. The dose was measured using a Faraday cup technique. The electron energy was 1 MeV and fluences of 10^{15}, 10^{16} and 2.6×10^{17} e/cm^2 were used. The proton energy was 800 keV and fluences of 10^{12}, 10^{13} and 10^{14} p/cm^2 were used. The measurements of transmission were made on the films

(1) Evelyn Anagnostou and Adolph E. Spakowski, "Transmission Effects on Plastic Films Irradiated with Ultraviolet Light, Electrons and Protons," NASA TM X-1905, 1969.

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immediately after their removal from the facility. The spectrophotometer used was a Beckman DK2.

The films irradiated by UV, electrons and protons were Teflon FEP, type C, Kapton, Mylar and Aclar 22A. The Aclar film was 1.5 mils (37 μm) thick. All of the other films were 1 mil (25 μm) thick. For the UV tests, the Mylar film was coated with Astro Epoxy adhesive.

Another series of UV tests was conducted on Teflon FEP-adhesive combinations. These adhesives had shown good bond strength when used on cells. They are Avery RVCT91, Transene Epoxy 30, Epotek 301 and Uralane XA8666. Also included in this test were FEP alone and FEP coated with Astro Epoxy.

RESULTS AND DISCUSSION

Ultraviolet Irradiation

The effect of UV irradiation on the transmission of the films is shown in figure 1. Two methods were used to irradiate the films. They differed only in that the small lamp either was or was not included. It has already been pointed out that the small lamp does not add to source intensity to any measurable degree (within the limits of the measurement method) so that its effect should come about from the amount of radiation which it produces at 0.186 μm (2 percent of its output).

Considering the results using all of the lamps, it can be seen from figure 1 that Kapton is not affected by irradiation up to 9500 ESH. Of the films tested, it is the most stable. Teflon-FEP is only mildly affected by this same test. It also has a much higher overall transmission, even at the end of the test (86 percent), than Kapton. Even if FEP continues to degrade at this rate, the film, used as a cover plastic, could give many more hours of service before its transmission reached that of Kapton.

Mylar coated with Astro Epoxy darkens quickly. After 1400 ESH, it has become as dark as Kapton. This darkening is not a sharp cutoff of the light at a particular wavelength. Rather, it is a general darkening across all wavelengths of concern (0.35-1.2 μm) with the greatest effect being, of course, at the lowest wavelengths.

The Aclar film became brittle quickly and had poor structural stability. In a very short time the film was in pieces and it could not be handled sufficiently to yield a sample large enough for transmission measurements. The film shrank in one direction and stretched in the other. Also deposits beneath the sample on the sample holder in the vacuum tank indicated that some chemical decomposition had occurred. X-ray analysis indicated the presence of phosphates in this deposit which may have been used in some manufacturing step.

Consideration of the results of the tests conducted without the small lamp as part of the source (solid symbols, fig. 1) show that Teflon FEP

does not darken as rapidly under those conditions. Similar results have been seen before (1) with weather-durable Mylar (Mylar-WD) and an experimental plastic, X101. Evidently, even a small amount of more energetic radiation can produce measurable darkening in some plastics. An explanation for why this does not occur with all plastic films is that each one will have a specific spectral absorbtivity. This source effect should make us cautious about the interpretation of results on plastics using different artificial solar sources such as mercury and xenon arc lamps. The films may react differently under actual solar radiation conditions in space. For this reason, an actual space experiment will have to be the final determinant of the film's usefulness as a solar cell cover.

For the other plastics besides FEP, shown in figure 1, the two methods of irradiation do not seem to be significantly different. Since Kapton is essentially a filter for all radiation below 0.450 μm, one would expect that the character of the ultraviolet source would be of little importance, as the data show. The effect on Aclar is rather difficult to determine, primarily because of its poor structural stability.

For Mylar coated with epoxy, no effect due to the low-pressure lamp is apparent except at the longest times. The difference in transmission as the test time increased is probably due to curling of the films. This essentially had the effect of decreasing the exposure time for the film irradiated with the small lamp included by about a factor of 0.89. The Mylar-Astro Epoxy combination is apparently so sensitive to any one or several of the strong lines of the mercury spectrum in the range between 0.2 and 0.3 μm that the more energetic radiation at 0.186 is of no consequence. Comparison of these data with data for Mylar-R in reference 1 shows that the addition of the epoxy is a drawback in respect to radiation resistance.

Included on figure 1 are data for the combination FEP-Astro Epoxy. This irradiation was conducted with the low-pressure lamp included. Comparison of these data with the measurements made on FEP alone indicate a serious problem area for cell applications. If FEP must be bonded to the cell with an adhesive, the adhesive itself must be resistant to radiation. The Clevite Corp. in bonding FEP to cells considered many adhesives. Unfortunately, one with very good radiation resistance, Sylgard 182, formed a poor bond between FEP and the cell. Several adhesives formed good bonds, however, and FEP films coated with these adhesives were irradiated in the UV facility. The resulting losses in transmission are shown in table I. Included for comparison are FEP-Astro Epoxy and FEP alone. The test was conducted for a total of 510 ESH. Originally, none of the adhesives lowered the overall transmission of the FEP drastically, but, after irradiation, the change in transmission varied greatly. The poorest in this respect was Epotek 301 which decreased in transmission 26 percent. The best adhesive was Astro Epoxy which lost 10 percent of its transmission. Considering the shortness of the test, it seems unlikely that

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an FEP-adhesive combination will prove useful for cell manufacture.

Proton and Electron Irradiation

The results of the electron and proton irradiation of Mylar, Kapton, Teflon FEP and Aclar are shown in table II. For 1 MeV electrons and fluences up to 2.6×10^{17} e/cm^2 the largest transmission loss occurs in Mylar. Aclar at this fluence was so brittle that it could not be handled. It appeared relatively clear, however. Also, no dimensional change was apparent as had been seen in the UV tests.

For 800 keV protons at fluences up to 10^{14} p/cm^2, no changes occurred in the transmission of the samples. Since all of these transmission measurements were made immediately after the films were removed from the test facility, it is assumed that annealing, if it occurred, was slight.

CONCLUSIONS

Kapton, the cell cover plastic presently in use, is unaffected by ultraviolet radiation for times up to 9700 ESH. This plastic is also unaffected by 1 MeV electrons at fluences up to 2.6×10^{17} e/cm^2 and 800 keV protons at fluences up to 10^{14} p/cm^2.

Teflon-FEP is mildly affected by UV but the magnitude of the effect depends on the spectrum of the source. The transmission of the film is unaffected by the electron and proton fluences already mentioned. The adhesives Astro Epoxy, Avery RVCT91, Transene Epoxy 30, Epotek 301 and Uralane XA8666 when used in combination with FEP decrease the tolerance of the package to UV and thus cannot be used for solar cell cover attachment. The FEP, when used as a cell cover, must be used alone or with a UV-resistant adhesive.

Mylar coated with Astro Epoxy is strongly affected by ultraviolet radiation. This combination darkens rapidly and in less than 2000 ESH has a lower transmission than Kapton. Mylar itself is darkened slightly by 1 MeV electrons although 800 keV protons up to 10^{14} p/cm^2 do not affect its transmission.

Aclar is very strongly affected by UV and 1 MeV electrons. The film becomes brittle and loses dimensional stability under UV. The electron fluence also embrittles the Aclar but does not affect the transmission greatly. Proton irradiation at the fluence previously mentioned does not affect this film.

The results of ultraviolet degradation studies must be interpreted cautiously. Present simulators do not accurately reproduce the solar ultraviolet spectrum. The spectral distribution may be more important than the overall ultraviolet intensity to the degradation of certain plastic films.
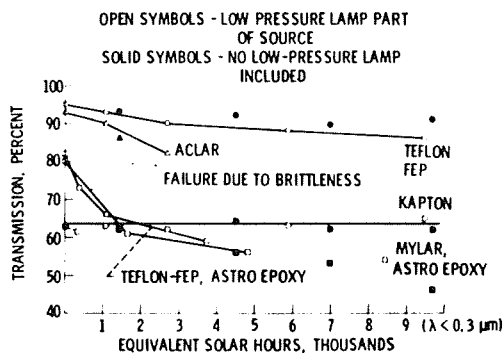

Figure 1. - Effect of UV irradiation on plastic films.

TABLE I

THE EFFECT OF UV IRRADIATION ON TEFLON-FEP,

ADHESIVE COMBINATIONS (510 ESH)

Adhesive	Original transmission %	Transmission at 510 ESH %	Transmission loss %
Astro Epoxy	82	72	10
Avery RVCT91	91	78	13
Transene Epoxy 30	91	78	13
Epotek 301	92	66	26
Uralane XA8666	93	75	18
None	96	94	2

TABLE II

EFFECT OF ELECTRON AND PROTON IRRADIATION

ON THE TRANSMISSION OF PLASTIC FILMS

Plastic	Transmission, %			
	Original	After electron fluence (1 MeV), e/cm^2		After proton fluence (800 keV) of 10^{14} p/cm^2
		10^{16}	2.6×10^{17}	
Mylar	87	86	82	87
Kapton	64	64	64	64
Teflon-FEP	96	96	96	96
Aclar	94	93	Too brittle to test	94